Chapter 23
Station Studies

23-1. Voltage Drop Studies

a. General. A preliminary voltage drop study for motor start-up as well as for motor-running conditions should be made during the initial design phase. The final study should be made during the approval drawing and data review phase of the project. The voltage drop study must be updated whenever the electrical system is revised. Computer programs are available to calculate the system's voltage dips and currents from motor starting to full load speed. For further information on voltage studies, refer to ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants and ANSI/IEEE 339, Power System Analysis.

b. Motor start-up. Motor start-up voltage drop depends on the motor inrush current. Depending upon the method of motor start-up, the inrush current ranges from two to six times the motor full-load current. Excessive starting voltage drop can result in problems such as motor stalling, nuisance tripping of undervoltage relays, motor overload devices, and temporary dips in lighting system brightness or restriking of high-intensity discharge lamps. During motor starting, the voltage level at the motor terminals should be maintained at approximately 80 percent of rated voltage or higher as recommended by the motor manufacturer.

c. Motor running. Undervoltage during the motor running condition may produce excessive heating in the motor windings, nuisance tripping of undervoltage relays and motor-overload devices, dim lighting, and reduced output of electric space heating equipment. Approximately 5-percent voltage drop from the transformer secondary terminals to the load terminals is acceptable.

23-2. System Protection and Coordination Studies

a. General. When a short circuit occurs in the electrical system, overcurrent protective devices such as circuit breakers, fuses, and relays must operate in a predetermined, coordinated manner to protect the faulted portion of the circuit while not affecting the power flow to the rest of the system.

(1) Isolation of faulted section. Isolation of the faulted section protects the electrical system from severe damage. It also results in efficient trouble shooting since the faulted section is downstream of the tripped protective device. Efficient troubleshooting results in reduction of costly repair time and system downtime.

(2) One-line diagram of electrical system. A one-line drawing of the electrical system is an important element of the protection and coordination study. The one-line diagram is discussed in detail in paragraph 23-3*c*.

b. Procedures. The coordination study is accomplished by overlaying protective device characteristic curves over equipment damage curves. This method is applicable in the range of fault clearing times greater than approximately 0.016 seconds (1 cycle) on a 60-Hz basis. For clearing times faster than this, as is the case for protecting solid state inverters, protection and coordination studies are achieved by comparing let-through energy (I-squared-t) values of current-limiting fuses (CLFs) to withstand energy values of the equipment being protected. Similarly, coordination between CLFs is achieved by comparing values of let-through energy of upstream fuses with the values of the melting energy of the downstream fuses.

(1) Protection and coordination study. A protection and coordination study may be performed manually or with the aid of a computer. Computer software is available with pre-programmed time-current characteristic curves. The result of the computer study can be automatically drawn onto standard time-current characteristic paper by the computer printer.

(2) Additional information. For further information on protection and coordination studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

c. Main disconnecting device. The utility supplying the power to the facility should be consulted regarding the type of protective device it recommends on the load side of the supply line which best coordinates with the source side protective device furnished by the utility.

d. Motors. Protective device characteristics must be coordinated with motor start-up characteristics. The devices must be insensitive enough to allow motors to start up without nuisance tripping caused by the relatively high magnitude of motor start-up current. The devices must be sensitive enough, however, to operate during overload or short-circuit conditions.

e. Transformers. Transformer protection is similar to that of motor protection as discussed above. The protective device must be insensitive to the transformer magnetizing in-rush current, but sensitive enough to operate for a short circuit condition. Note, the new ANSI standard on transformer protection (ANSI/IEEE C57.109) could be used as an alternative to the classic method of transformer protection. Transformer magnetizing inrush should be specified as 8 X full-load current for transformers rated less than 3 MVA, and 12 X full-load current, otherwise.

f. Cables. Cable protection requires coordinating the protective device characteristics with the insulation smolder characteristics of the power cable. The insulation smolder characteristics of the cable are the same as the "short-circuit withstand" and "short-circuit heating limits" of the cable.

g. Specification requirements. The pump station construction specifications should require the contractor to furnish the completed protection and coordination study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clearly stated in the specifications that it is the contractor's responsibility to coordinate with his various equipment suppliers to produce a complete and accurate protection and coordination study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The construction specifications should require the contractor to submit the following items as one complete submittal:

(1) Full-size reproducibles of protective device characteristic curves.

(2) The motor-starting characteristics in the form of time versus current curves or data points.

(3) Data indicating the short-circuit withstand capability of motor control centers, panelboards, switchgear, safety switches, motor starters, and bus bar and interrupting capacities of circuit breakers and fuses.

(4) Transformer impedance data. These data should be submitted in one of three forms: percent IR and percent IX, percent IZ with X/R ratio, or percent IZ with no load and total watt losses.

(5) Cable insulation smolder temperature.

(6) Completed time-current coordination curves indicating equipment damage curves and device protection characteristics.

(7) A marked-up one-line diagram indicating ratings and trip sizing of all equipment.

23-3. Short-Circuit Studies

a. General. Short-circuit calculations are necessary in order to specify equipment withstand ratings and for use in conjunction with the protective device coordination study. Switchgear, motor control centers, safety switches, panelboards, motor starters, and bus bar must be capable of withstanding available fault currents. After the available fault current has been calculated at each bus in the electrical network, the available fault current withstand ratings are specified.

(1) Circuit breakers. Circuit breakers must be capable of withstanding the mechanical and thermal stresses caused by the available fault currents. They must be able to remain closed even though tremendous forces are present in such a direction as to try to force the breaker contacts open. The ability of circuit breakers to remain closed is indicated by their momentary ratings. The momentary rating is a function of the circuit breakers interrupting rating, which is the ability to interrupt a fault current without incurring excessive damage to the breaker.

(2) Fuses. Fuses must also be capable of safely interrupting fault current and are rated in terms of interrupting capacity.

(3) Motor starters. Motor starters furnished with motor circuit protectors are available with short-circuit withstand ratings up to 100,000 amperes. Starters furnished with fusible switches are available with withstand ratings up to 200,000 amperes.

b. Procedures. The basic elements of a short-circuit study are the short-circuit calculations and the one-line diagram of the electrical system. For pumping stations the three-phase bolted fault is usually the only fault condition that is studied. Utility systems line-to-ground faults can possibly range to 125 percent of the three-phase value, but in pumping plants line-to-ground fault currents of greater magnitude than the three-phase value are rare. Line-to-line fault currents are approximately 87 percent of the three-phase fault current.

(1) Preliminary short-circuit study. A preliminary short-circuit study should be prepared during the design phase of the project. The final study should be prepared by the pump station construction contractor as described below.

(2) Calculations. The magnitude of the fault currents can be calculated using long-hand methods. However, software is available to reduce preparation time and simplify the task for large complex systems.

(3) Additional information. For further information on short circuit studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

c. One-line diagram. Plate 13 indicates the format of the one-line diagram developed as part of the preliminary and final protection and coordination and short-circuit studies. Plates 15 and 16 are typical of one-line diagrams to be issued with the plans and specifications.

(1) Standard symbols. Standard symbols for use on the one-line diagram are listed in ANSI Y32.2. Any nonstandard symbols that are used to show special features or equipment should be explained in the drawing legend to make their meaning entirely clear.

(2) Check list. The following is a check list of items that should be included on the study one-line diagram:

(a) Fault current. This is the available three-phase fault current of the utility supply at the pumping station metering point. This information can be presented in amperes, MVA, or as an impedance to the utility infinite bus (impedance in ohms or per unit on a specified base). The designer should also request the utility to provide an estimate of future three-phase fault levels. The estimate provides an indication of utility system changes which may affect the future short-circuit interrupting capability and withstand ratings of installed electrical equipment.

(b) Bus voltage.

(c) Transformers. The diagram should show winding connections, KVA rating, percent impedance, the X/R ratio, neutral grounding, if any, including the neutral ground impedance value, if not solidly grounded.

(d) Power cables. The diagram should show size, length, conductor material, whether single or multi-conductor, and whether the cable is carried in a magnetic or nonmagnetic duct.

(e) Circuit breakers. The diagram should show type by appropriate symbol (for example, molded case or draw-out) and the following ampere ratings: interrupting rating, frame size, thermal trip setting, and magnetic trip setting. It should show also the range of adjustment of the magnetic trip, if adjustable, as well as the recommended setting as determined by a protective device coordination study.

(f) Switches and fuses. The diagram should show type of fuse or switch and the continuous and interrupting rating in amperes.

(g) Motors. The following should be given: horsepower or kilowatt rating, power factor, synchronous or induction type, mechanical speed (revolutions per minute), and subtransient reactance. The following additional data are required for synchronous machines: transient reactance, synchronous reactance, and the impedance of any grounding resistor.

(h) Location(s) where power purchased from a utility company is metered.

(i) The following information is required for preparation of the protection and coordination study: locations of potential and current transformers and relays and metering. Show location, quantity, and types of relays by standard IEEE device numbers, such as 51 for overcurrent relays, 67 for directional overcurrent relays. Device numbers are listed in ANSI/IEEE C37.2.

d. Specification requirements. The pump station construction specifications should require the contractor to furnish the final short-circuit study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clear in the specifications that it is the contractor's responsibility to coordinate with his various equipment suppliers to produce a complete and accurate short-circuit study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The specifications must state that the cable sizes, ampere ratings of the protective devices, and the short-circuit withstand ratings of the equipment shown on the one-line diagram are preliminary and that the contractor shall furnish a complete and final one-line diagram upon completion of the coordination and protection and short-circuit studies.